BELLCOMM, INC.
955 L'ENFANT PLAZA NORTH, S.W. WASHINGTON, D. C. 20024

B70 07068

SUBJECT: The Effects of Navigation Range Errors when an LGC Lurain Model is Used for Littrow - Case 310

DATE: July 15, 1970

FROM: F. LaPiana

ABSTRACT

Navigation range errors spanning ±3700 feet are evaluated for their effect on the LM descent trajectory and on the Landing Point Designator (LPD). Comparisons are made of cases both with and without a LM guidance computer lurain model, and with and without landing site redesignations back to the 'a priori' preselected site.

For the Littrow approach, the addition of a lurain model greatly reduces lurain induced trajectory perturbations. A simple five segment model brings the trajectory profile very near the design shape.

The LPD system accuracy is significantly improved by the use of a lurain model. This is true even in the presence of large navigation range errors. The use of a lurain model should reduce unnecessary LPD activity by better indicating the actual landing site to the LM pilot.

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MEMORANDUM FOR FILE

INTRODUCTION

This study was performed to evaluate the effects of navigation range errors when the Lunar Module Guidance Computer (LGC) uses a lurain model. Any navigation error leads directly to a lurain model/lurain mismatch. This induces errors in the LGC estimate of altitude above the landing site, which is then propagated into all related calculations.

The data used for this study was generated using the Bellcomm Powered Flight Performance Simulation (PFPS) computer program. The lurain profile for Littrow was taken from Reference 1.

PROCEDURE

The LGC lurain model used was constructed of five straight-line segments and was implemented in the simulation as it will be in the LGC as specified in Reference 2. Integrated PFPS trajectories with an LGC lurain model were flown for a total of 14 cases. In each of the first seven cases, the initial downrange navigation error was allowed to persist to touchdown. In the second group of seven cases, the same initial navigation errors were compensated for by the simulation of crew input Landing Point Designator (LPD) pulses. The pulses were calculated during the simulation and are based on the angular vertical separation between the pre-mission selected ('a priori') landing site (such as the Surveyor spacecraft on Apollo 12) and that indicated by the LGC through the Display and Keyboard (DSKY) readout for the LPD scale on the LM window. This angular separation is a function of the navigation error and of the difference between the actual and LGC altitude, since altitude errors generate LPD errors. The altitude error is caused by three factors: 1) a mismatch of the LGC lurain model and the actual lurain due to navigation range errors, 2) the difference between the lurain model and the lurain when there is no range mismatch, 3) and, the time delays due to the radar weighting function. The angular vertical separation is truncated to the nearest one-half degree to match the LPD pulse size. In this analysis pulses are inhibited when the LGC estimate of altitude is over 4000 ft and also when the time left in the Visibility Phase is less than 20 seconds. The 4000 ft altitude restriction provides a realistic "crew situation appraisal delay" of about 28 seconds from a 7000 ft high-gate altitude. The current LGC Software does not permit LPD pulses within 20 seconds of the automatic switch from the Visibility Phase to the landing phase. Thus, the LPD is inoperative from an altitude of about 200 ft to touchdown on an automatic descent. (Of course, the crew nominally takes over control manually at about 500 ft altitude.)

It is important to know that the lurain model is referenced to the point the LGC is trying to reach. If LPD corrections are made which move the target uprange or downrange, the terrain model moves with the target. This is desirable if the LPD is used to reach the 'a priori' site, but not desirable if the pilot abandons that site for another some distance away. To help overcome this problem, the MSC Software Configuration Control Board is presently considering the value of deleting the lurain model entirely when the landing phase (P66) is entered from the Visibility Phase (P64).

DISCUSSION

Figure 1 is a trajectory profile which illustrates the error in the LGC estimate of position induced by radar updates when there is no LGC lurain model. Figure 2 clearly shows the improvement of the LGC estimate of position when a lurain model is used. (This case has no navigation range error.) But of greater importance is the change in the actual position trace induced by the inclusion of the lurain model. The trajectory is now much closer to the design profile because of the reduction of altitude (relative to the landing site) errors from the landing radar updates. Another important consideration is the amount of LPD activity likely to occur in these two cases. Without a lurain model, even with no navigation errors, the crew sees the desired landing site at a different spot than the LPD indicates and will be tempted to redesignate (as occurred on Apollo 12). With the lurain model, the distance is reduced and, therefore, unnecessary LPD activity should be reduced significantly.

The family of Visibility Phase trajectory profiles in Figure 3 shows the effect of uncorrected navigation errors of ±1200 ft, ±2400 ft, and ±3700 ft.* The droop in the profiles

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*The current 3σ touchdown dispersion ellipse has a downrange semiaxis of about 3200 ft.

of those cases landing short is induced by the radar sensed lurain being a mismatch to the LGC lurain model which is indexed to the guidance coordinate frame centered at the actual landing site in each case. This droop could cause site wash-out if the sun angle is near 9° whereas on a nominal descent, wash-out is not severe until the sun elevation is near 13°.

Figure 4 shows the family of profiles for the same navigation range errors as before, but with LPD redesignation during the Visibility Phase, back to the 'a priori' site. The LGC lurain model is shown indexed to the site, as it would be after the LPD redesignation. The very pronounced trajectory droop for the positive range error cases is caused by the LPD "long" redesignations required. Wash-out could occur at sun angles near 6° for the case when LPD pulses totaling 3700 ft down range are entered. The ΔV used to redesignate back to the original site was in all cases less than 75 fps.

On the remaining graphs, all curves with the prefix N are cases where an LGC lurain model was not used, and all curves with the suffix A are cases where the LPD was used to redesignate back to the 'a priori' landing site. Figures 5, 6 and 7 are plots of the LGC calculated LPD angle against Visibility Phase time. Figure 5 shows the effect on the LPD angle of changing the LGC estimate of position profile by adding the lurain model, with no navigation range errors, as shown in Figures 1 and 2. Figure 6 shows the LPD angle time history for the cases where the navigation range error is +3700 ft (plus indicates the LM would land short of the desired landing site if unredesignated). The curves 3700A and N+3700A are for the cases where LPD pulses are used to move the landing point downrange to the 'a priori' site and hence correct for the navigation error. The dip at about 60 seconds in curve N+3700 (no LGC lurain model) is a lurain effect, the irregularity of N+3700A is the lurain/LPD interaction effect. Figure 7 shows the pronounced effect on the LPD angle of a -3700 ft navigation error. The curves marked -3700 and N-3700 are for the cases where the LM lands 3700 ft downrange of the 'a priori' site. The curves -3700A and N-3700A are for the cases where the LPD is used to redesignate uprange back to the desired landing point. The danger of uprange redesignations causing loss of sight of the site is very apparent when the line-of-sight calculated by the LGC is very near the bottom of the LM window (as shown in Fig. 7). Site visibility time is markedly reduced by the uprange redesignations.

Another problem caused by LGC altitude errors relative to the actual landing site, is that the LPD indicated site is not the point to which the guidance computer is flying the LM. Thus the pilot is led to assess the wrong area, which only gradually moves to the LGC target. The quantity "DIST" is computed in the simulation as the lunar surface distance between these two points, and Figures 8, 9 and 10 present data on "DIST" vs. time for the cases corresponding to Figures 5, 6 and 7 respectively. (If the LPD indicates a point downrange of the LGC targeted spot, "DIST" is negative.)

Figure 8 shows the advantage of using a lurain model for Littrow. This case is for zero navigation range error, and shows the over ten-fold reduction in the maximum value of DIST under these conditions. Figures 9 and 10 show the time histories of DIST for ±3700 ft navigation range errors, with and without LPD return to the 'a priori' site. Even with these initial position errors, the value of DIST is reduced significantly by the inclusion of a lurain model.

Very closely related to the DIST plots are Figures 11, 12 and 13 which show the corresponding error in the LGC LPD angle (ERRLPD). This error is computed as the angle between the LPD line-of-sight and the line connecting the LM to the current LGC guidance landing site.

Figure 11 compares ERRLPD for the cases where a lurain model is not used against one where it is used with no navigation range error. In the former, a 2.86° error is reached early in the Visibility Phase where it corresponds to a 4133 ft value of DIST. The case where a lurain model is used reaches an ERRLPD value of -1.32° late in the phase, corresponding to a DIST of -112 ft. This is caused by a mismodelling of the lurain.

Figures 12 and 13 show the time histories of ERRLPD for the ±3700 range error cases. Where the LPD is used to return to the 'a priori' site, the curves naturally converge on the "no navigation range error" cases of Figure 11. A comparison of the ±3700 curves of Figures 12 and 13 shows the effect on ERRLPD of landing at displaced sites, which induces altitude errors.

The importance of effects which occur below altitudes of 500 ft should be evaluated in light of the probability that the astronauts will manually take over control at around that altitude.

The LM pitch profiles are relatively insensitive to navigation range errors during the braking phase. The principal perturbing effect in the Visibility Phase is use of the LPD to correct the navigation errors. The "short" redesignation needed with a -3700 ft navigation error causes a maximum pitch-back of 10° from nominal. The "long" redesignation to correct for a +3700 ft error causes a pitch-forward of 7° from the nominal attitude. Both these maximums occur about 7 seconds after the first LPD pulses are input.

CONCLUSIONS

For the approach to the Littrow landing site, the lurain profile induces considerable trajectory perturbation if not modeled in the LGC. Using a simple five point lurain model returns the trajectory profile to essentially the design shape.

A positive navigation range error, which causes a "short" landing, induces trajectory droop. This situation is aggravated considerably if "long" LPD redesignations are used to return the LM to the 'a priori' site.

Negative range errors do not produce major undesirable effects on the trajectory shape, but they do shorten site visibility time. The LPD angle is adversely affected by negative range errors and could cause loss of sight to the site if the range error is more than -3700 ft.

The LPD system accuracy is considerably improved by the use of a LM lurain model even when large navigation range errors exist. As a result, unnecessary LPD activity should be reduced significantly.

Based on the criteria evaluated, the beneficial effects of using a LGC lurain model are not negated even when navigation errors as great as ±3700 ft exist. This conclusion is specifically for the Littrow approach, and should not be generalized to other landing sites without further evaluation, since results are dependent on the specific lurain profile used.

F. LaPiana

2014-FL-bsb

F. LaPiana

Attachments

REFERENCES

1. "Profiles of Littrow," TJ3/Chief, Photogrammetry and Chartography Branch, NASA, MSC, Paul E. Norman, NASA, MSC IOC TJ-69-1104, December 24, 1969.

2. "SCB Meeting Number 36, Spacecraft Software Configuration Control Board Program Change Request #1025," J. E. Williams, Jr., NASA, MSC, 70-FS55-49, February 27, 1970.

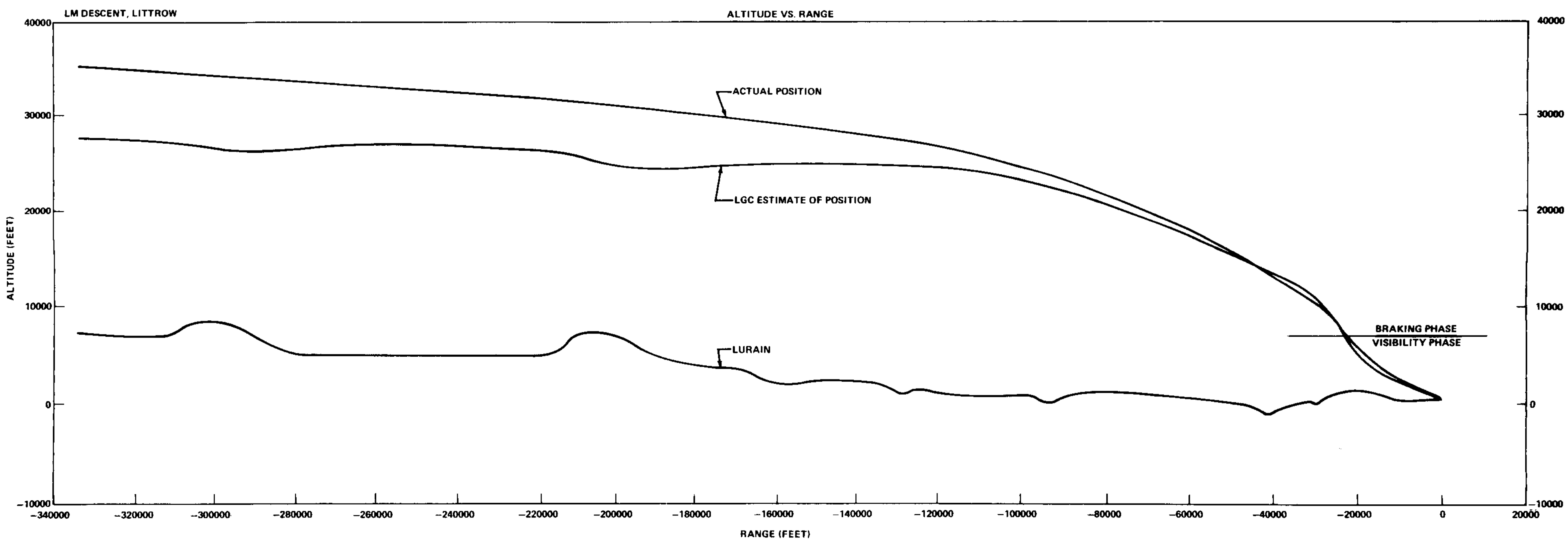

FIGURE 1 - TRAJECTORY PROFILE, LITTROW APPROACH WITHOUT LGC LURAIN MODEL

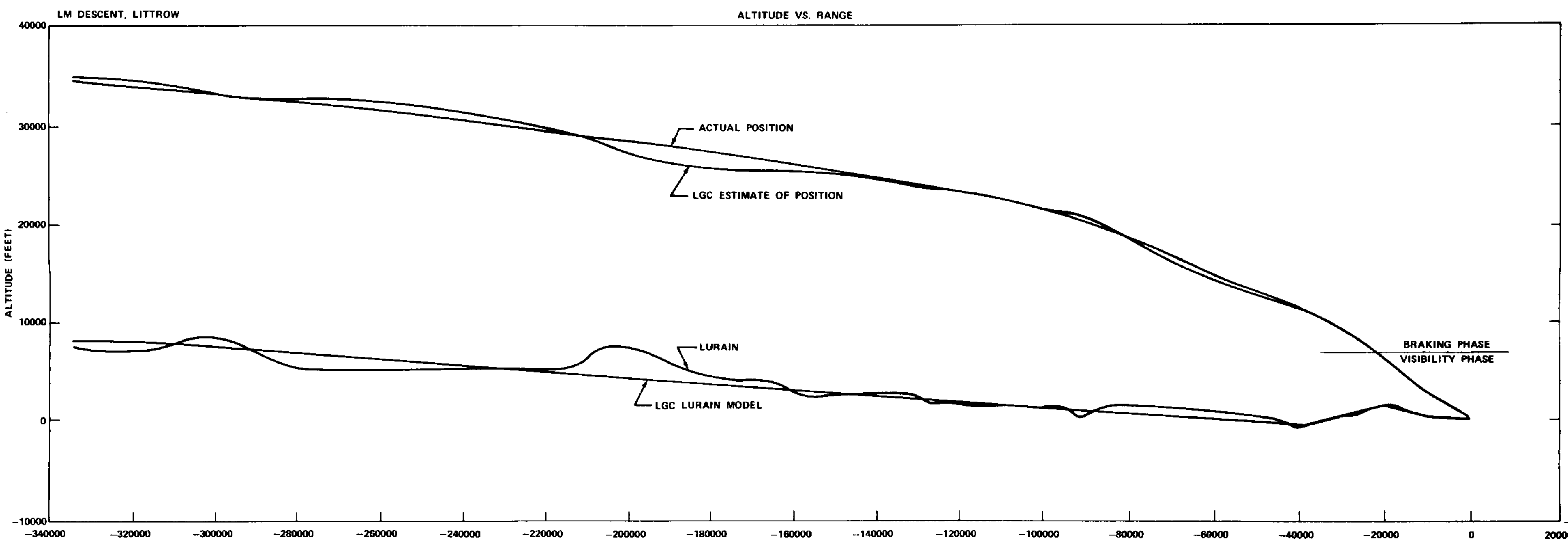

FIGURE 2 · TRAJECTORY PROFILE, LITTROW APPROACH WITH LGC LURAIN MODEL

ALTITUDE VS. RANGE

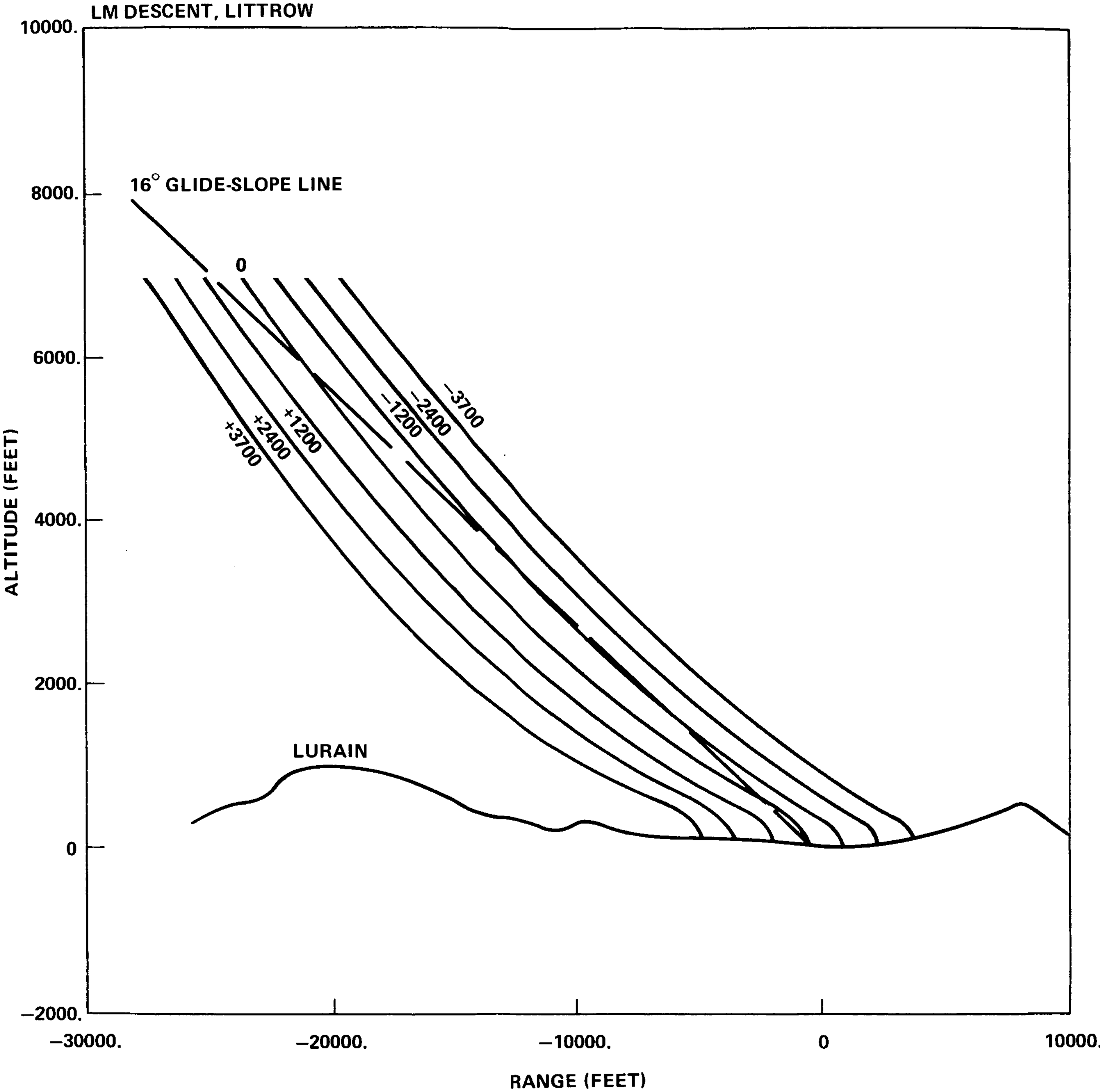

FIGURE 3 - VISIBILITY PHASE, 0′, ±1200′, ±2400′, ±3700′
NAVIGATION RANGE ERRORS, UNREDESIGNATED

ALTITUDE VS. RANGE

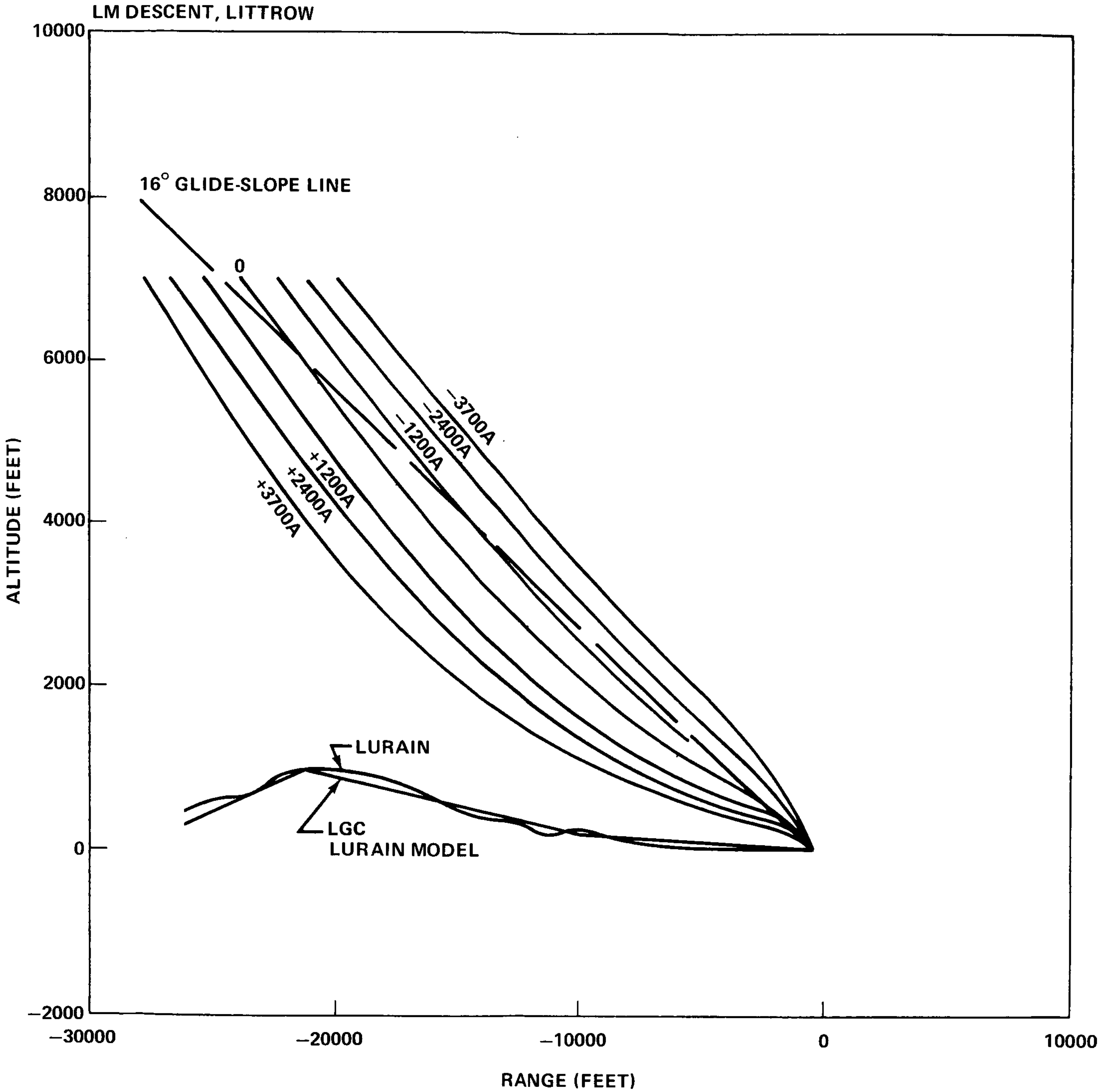

FIGURE 4 - VISIBILITY PHASE, 0′, ±1200′, ±2400′, ±3700′
NAVIGATION RANGE ERRORS, LPD TO LANDING SITE

LPD ANGLE VS. TIME

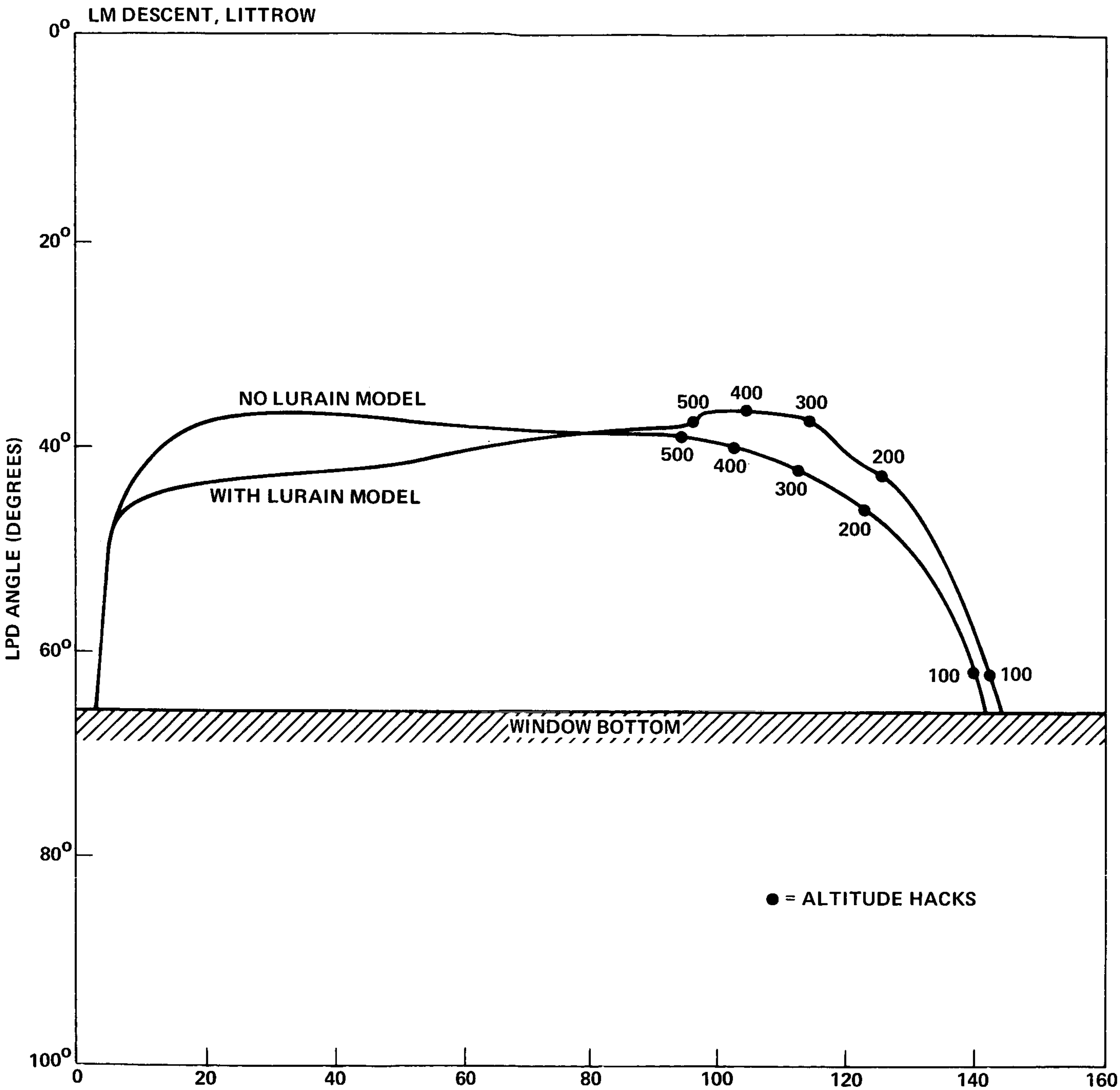

FIGURE 5 - VISIBILITY PHASE, LITTROW APPROACH
NO NAVIGATION RANGE ERROR

LPD ANGLE VS. TIME

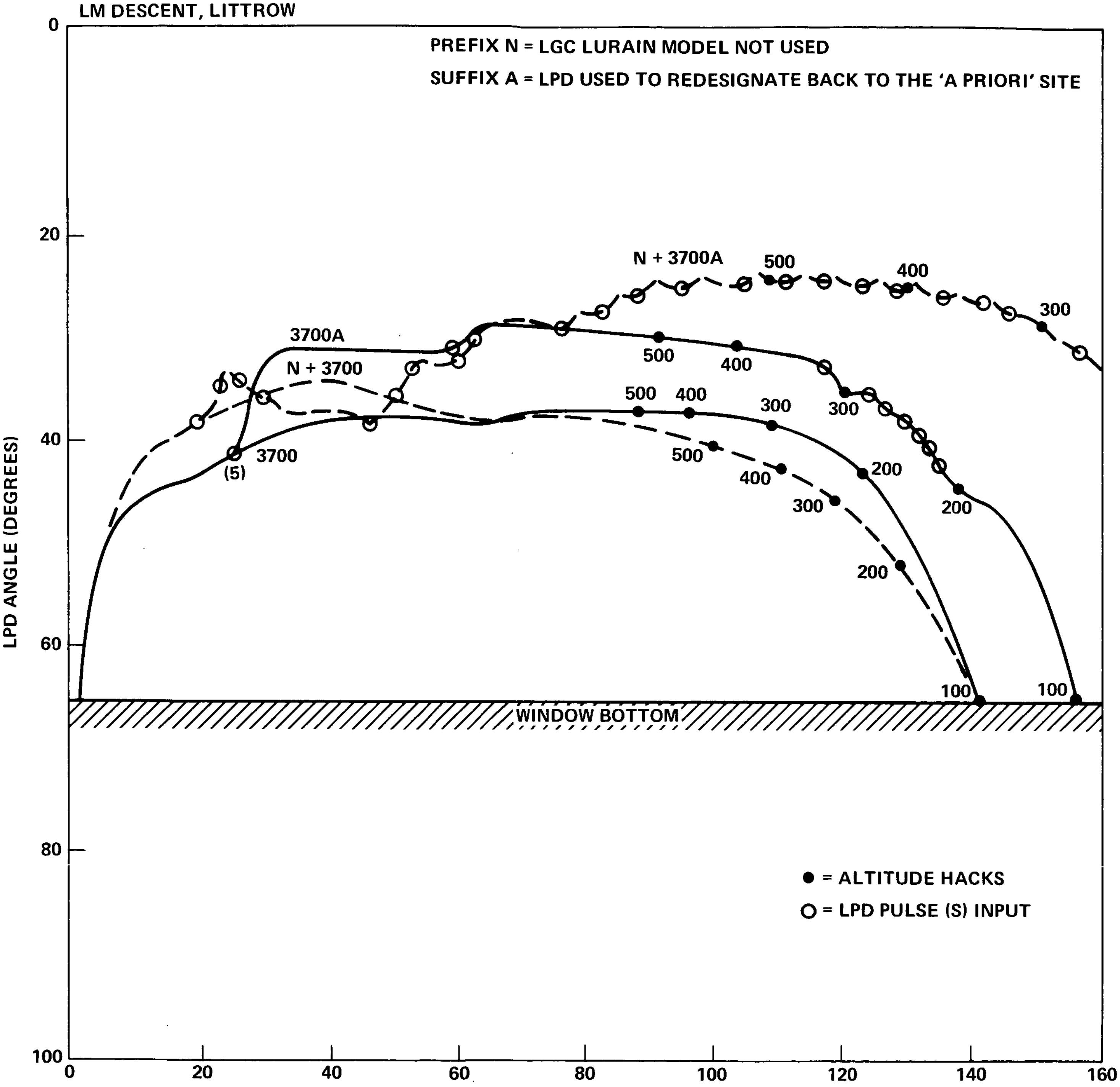

FIGURE 6 - VISIBILITY PHASE, LITTROW APPROACH
+ 3700 FT NAVIGATION RANGE ERROR

LPD ANGLE VS. TIME

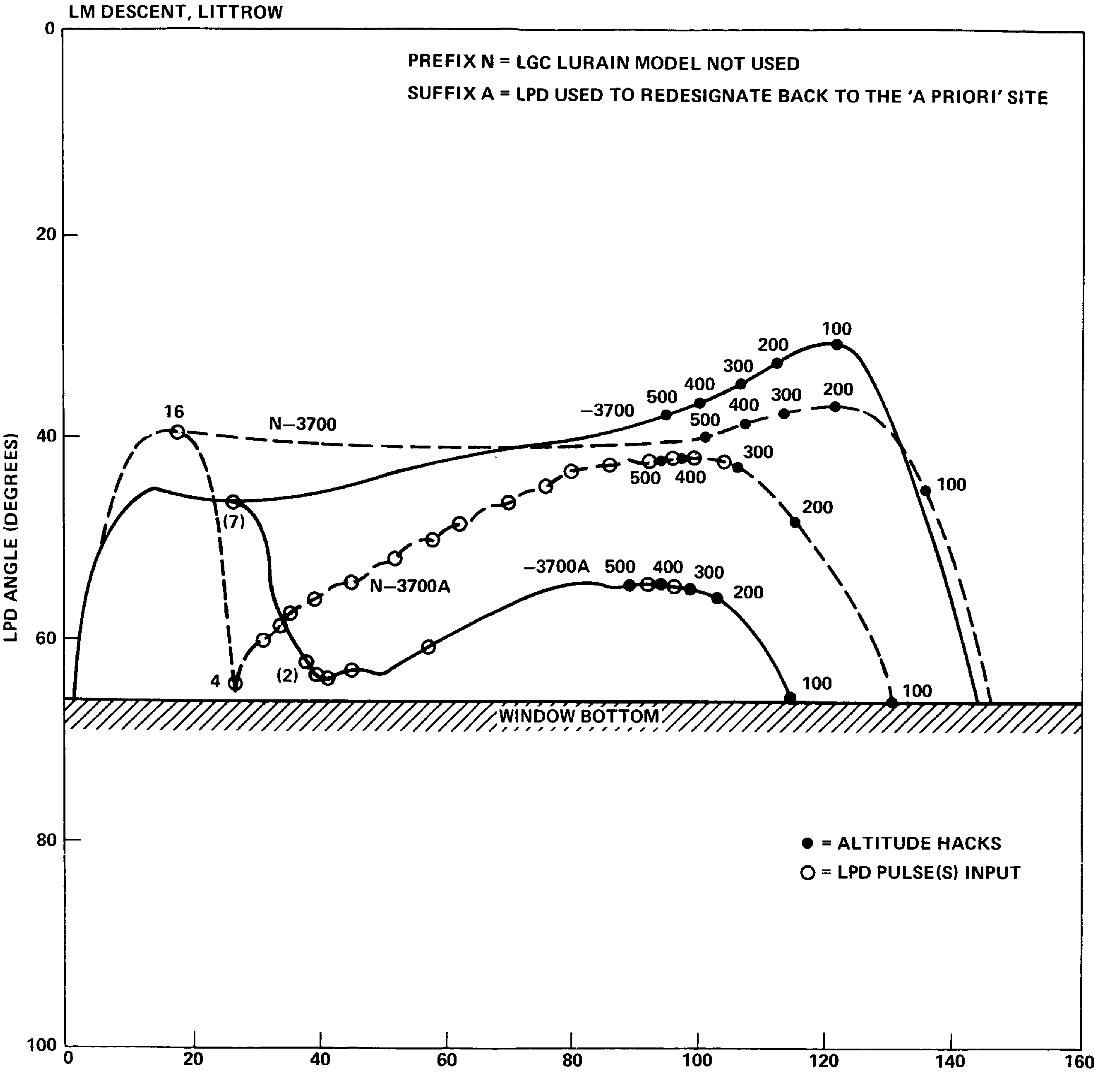

FIGURE 7 - VISIBILITY PHASE, LITTROW APPROACH
–3700 FT NAVIGATION RANGE ERROR

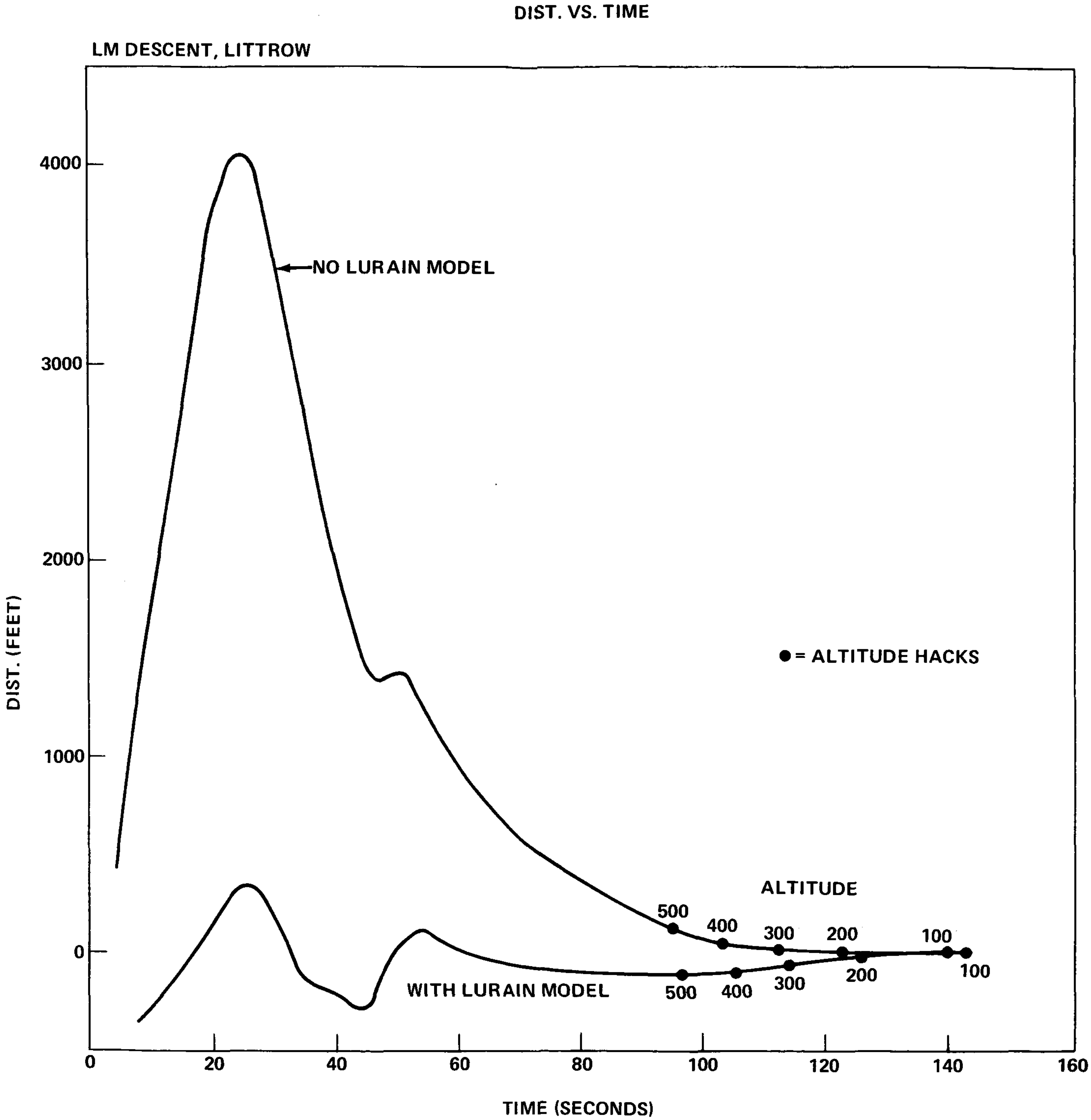

FIGURE 8 - VISIBILITY PHASE, LITTROW APPROACH
NO NAVIGATION RANGE ERROR

DIST VS. TIME

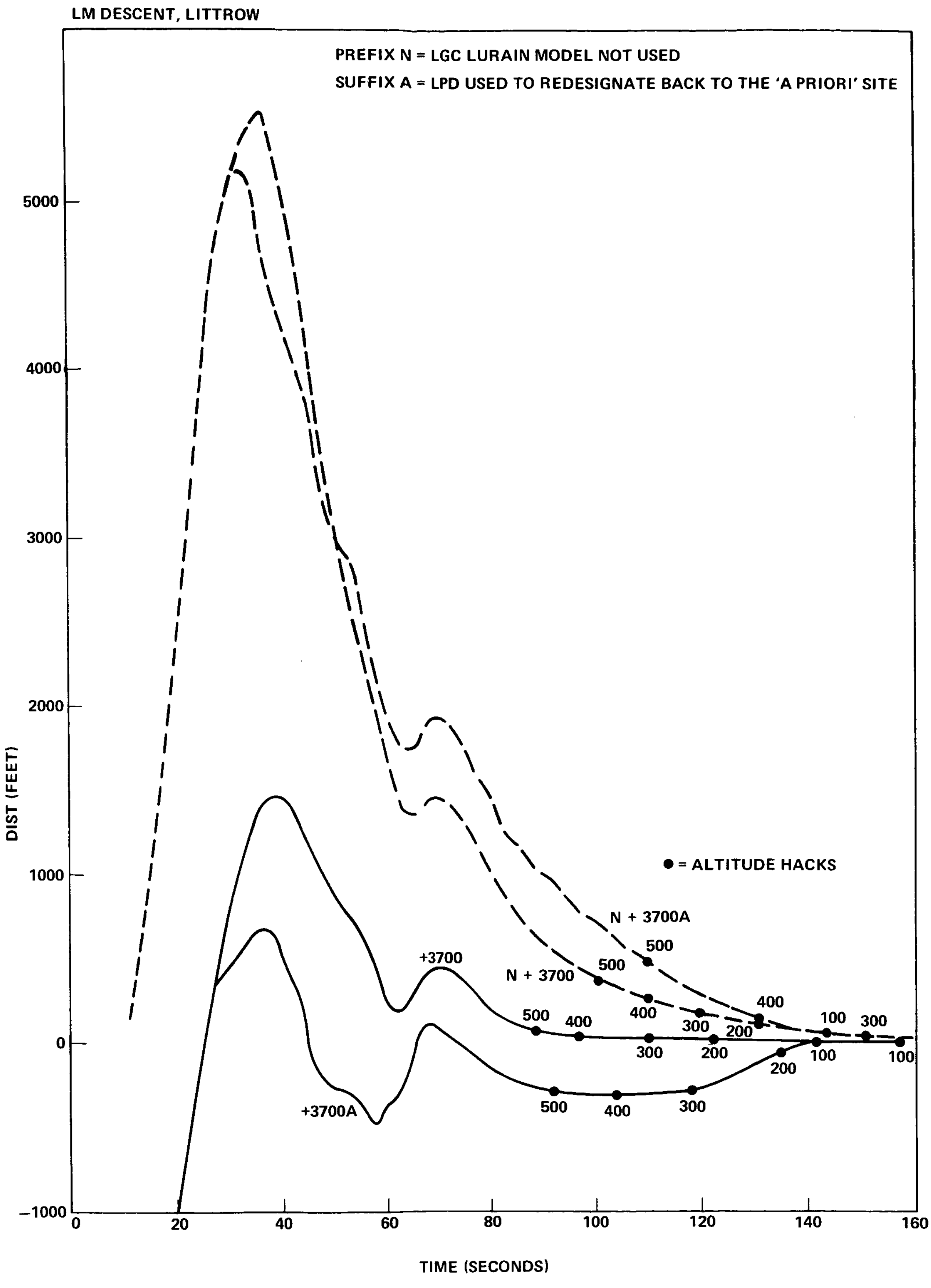

FIGURE 9 - VISIBILITY PHASE, LITTROW APPROACH, + 3700 FT NAVIGATION RANGE ERROR

DIST VS. TIME

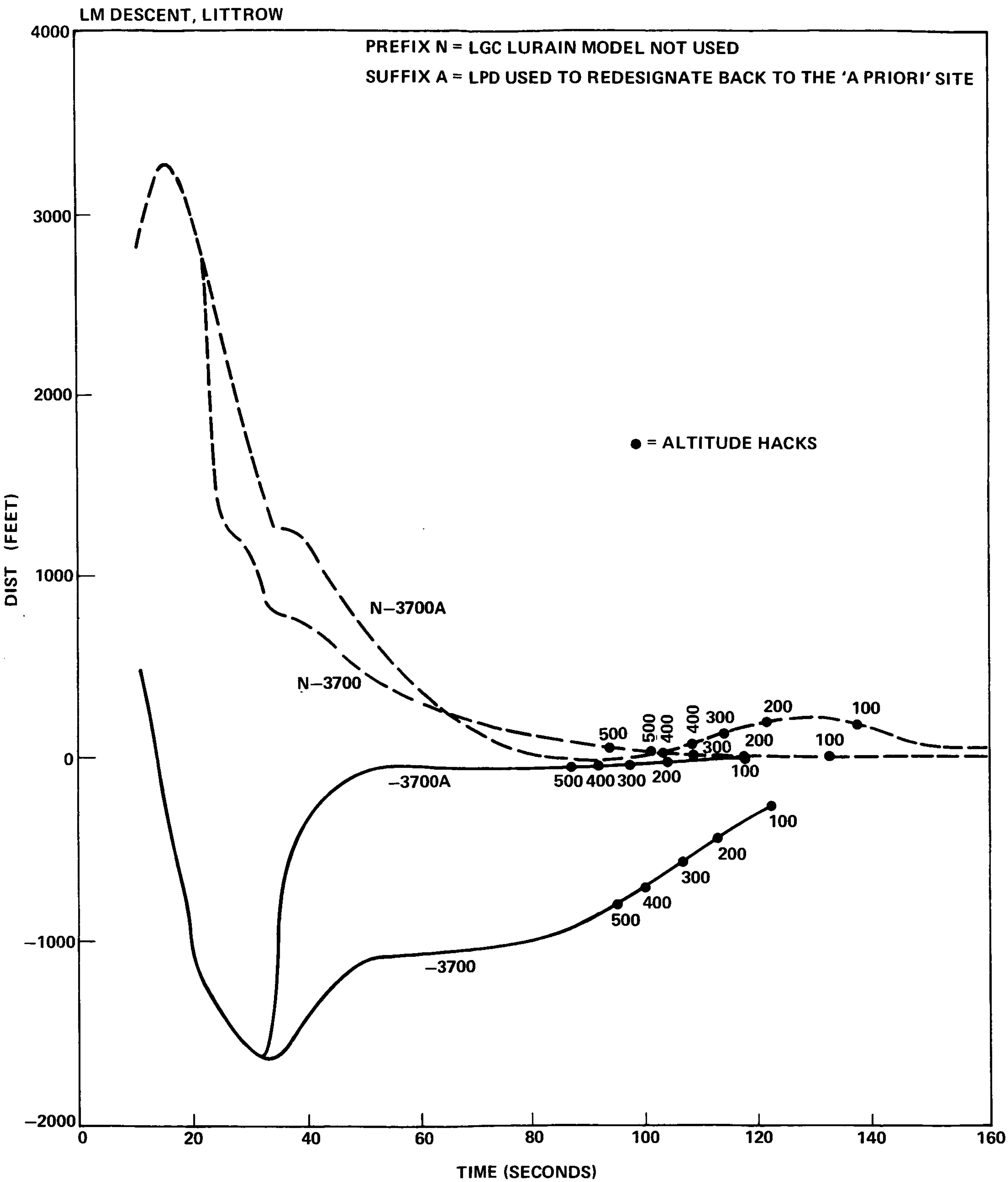

FIGURE 10 - VISIBILITY PHASE, LITTROW APPROACH
−3700 NAVIGATION RANGE ERROR

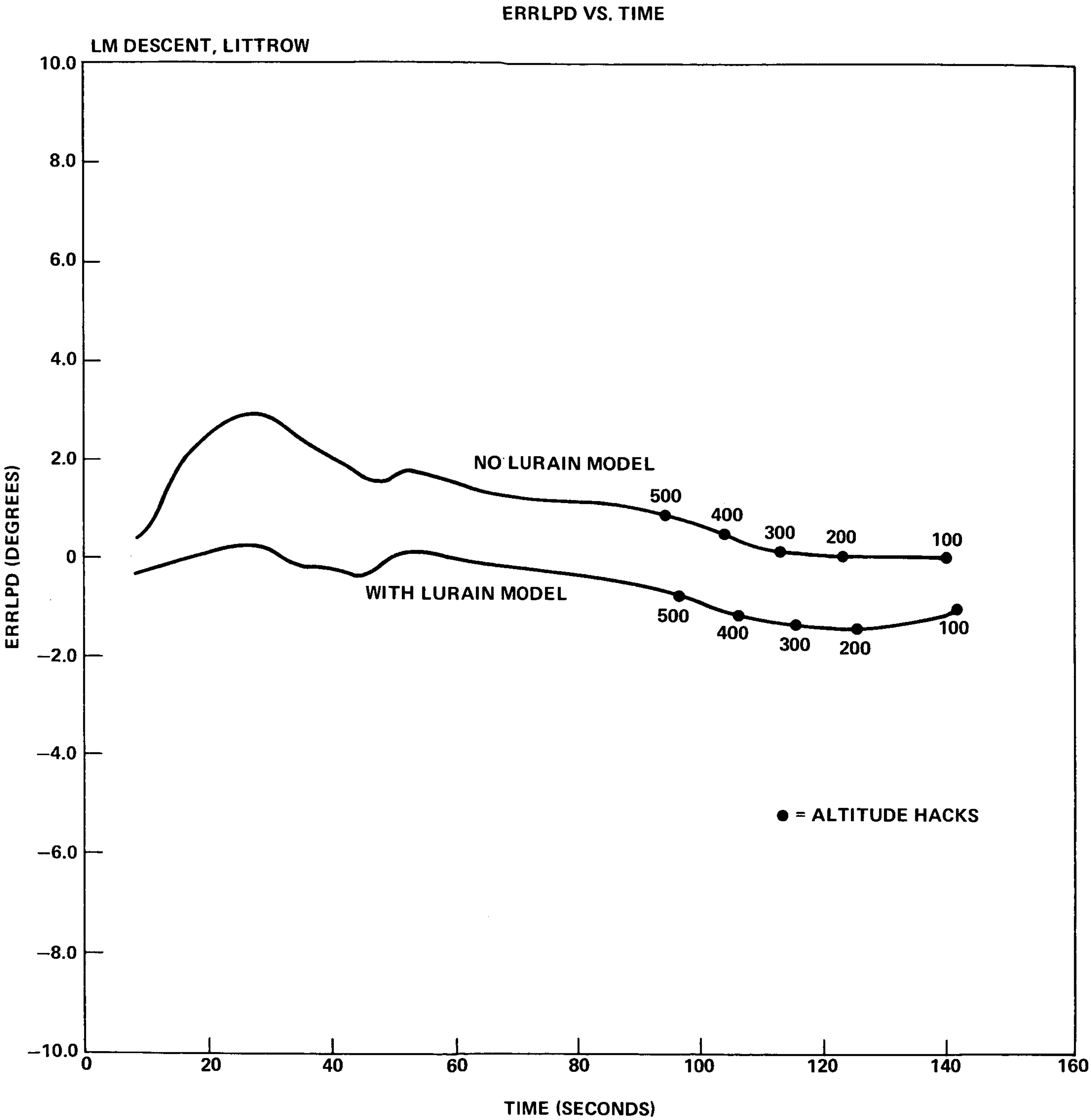

FIGURE 11 - VISIBILITY PHASE, LITTROW APPROACH,
NO NAVIGATION RANGE ERROR

ERRLPD VS. TIME

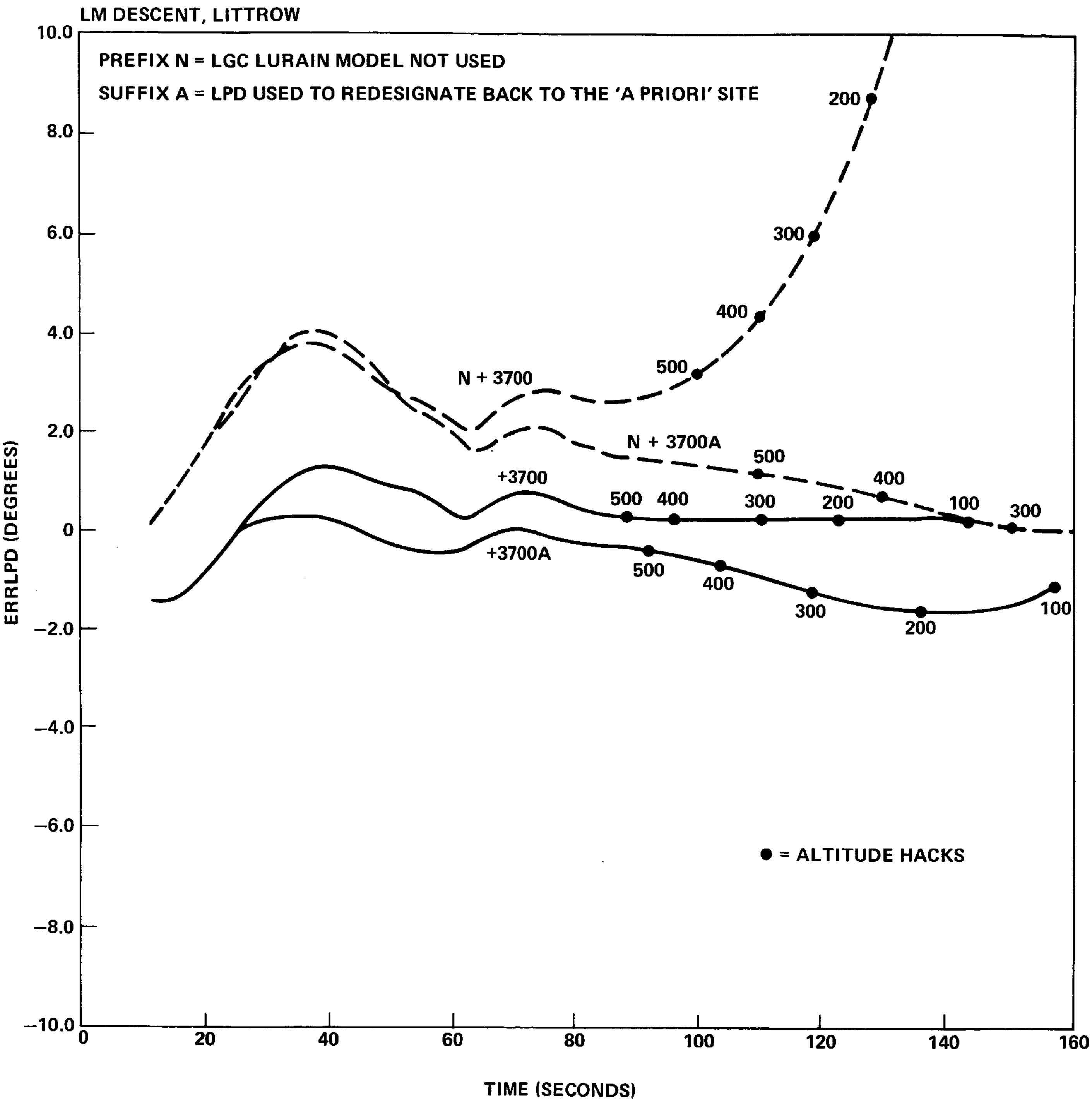

FIGURE 12 - VISIBILITY PHASE, LITTROW APPROACH, +3700 FT NAVIGATION RANGE ERROR

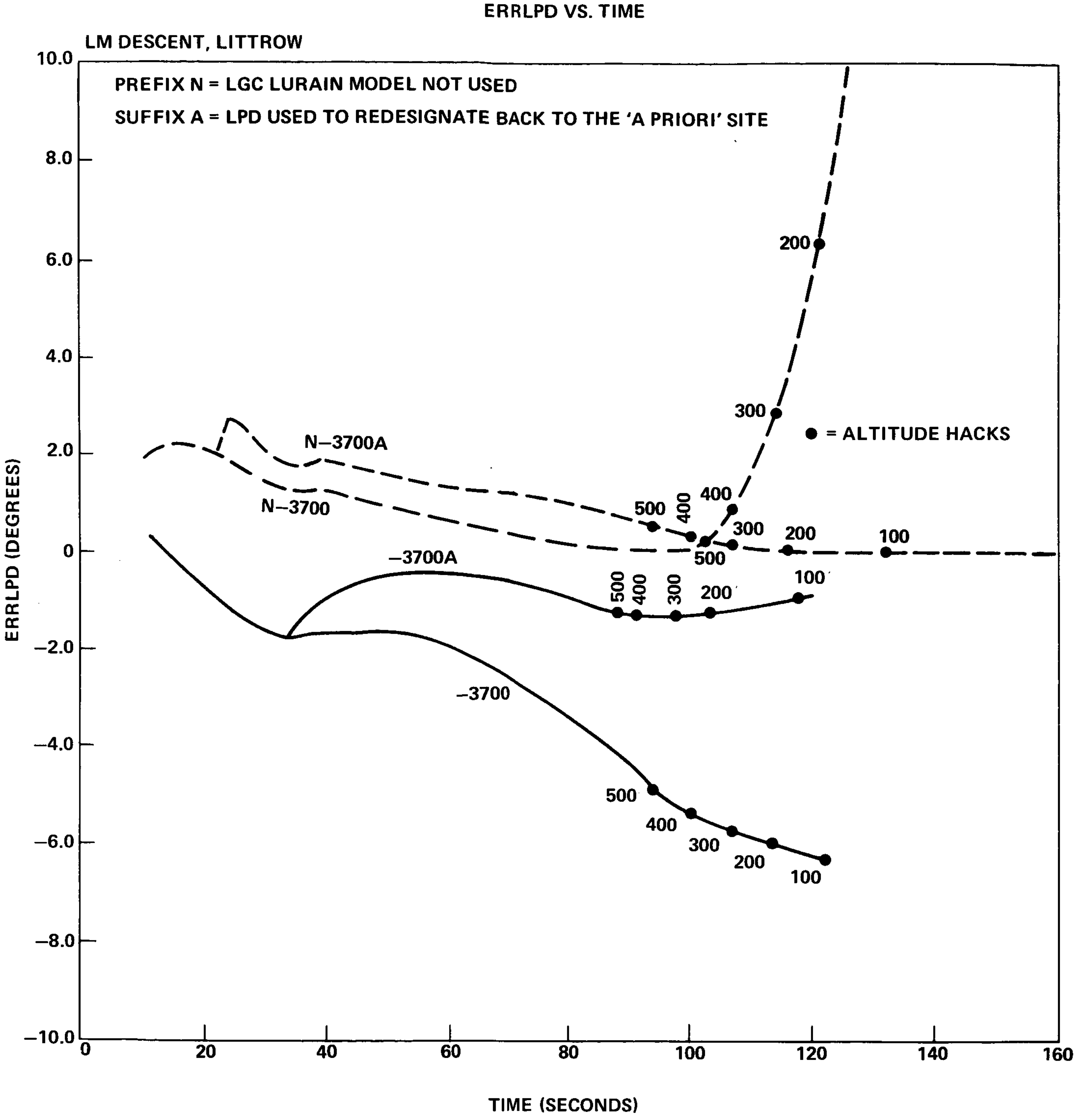

FIGURE 13 - VISIBILITY PHASE, LITTROW APPROACH
–3700 FT NAVIGATION RANGE ERROR